An A-Train View of Atmospheric Response to 2009-10 El Niño

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Introduction

- The winter of 2009-2010 was characterized as the strongest "Central-Pacific (CP) El Niño" in the past three decades (Lee and McPhaden, 2010).
- The atmospheric response to this El Niño was captured by a suite of A-Train satellite instruments.
- The clouds and water vapor changes during this El Niño are examined with the new satellite observations.

Questions to Answer

- What are the vertical profiles of clouds and water vapor response to El Niño?
- Are the changes in clouds and water vapor driven by dynamic circulation change or thermodynamic changes (SST, SST pattern, or other factors)?
- How do atmospheric responses to “Central-Pacific (CP) El Niño” differ from those to “Eastern-Pacific (EP) El Niño”?
- Is El Niño a test bed for global warming?

Data Used

CloudSat/CALIPSO

The Level 2 cloud water content (CWC) profiles (2B-CWC-RO) from CloudSat and cloud fraction from combined radar and lidar measurements (2B-GEOPROF-LIDAR) are used. Data are available since June 2006.

Aura MLS

The Level 2 upper tropospheric (UT) ice water content (IWC) and water vapor profiles (V2.2) are used. Data are available since August 2004.

Aqua AIRS

The Level 3 water vapor profiles (V5) are used. Data are available since September 2002.

NCEP/NCAR Re-analysis

Monthly mean optimum interpolated SST (December 1981 to September 2010, 1º ×1º) and vertical velocity at 500 hPa are used.

The SST Anomalies

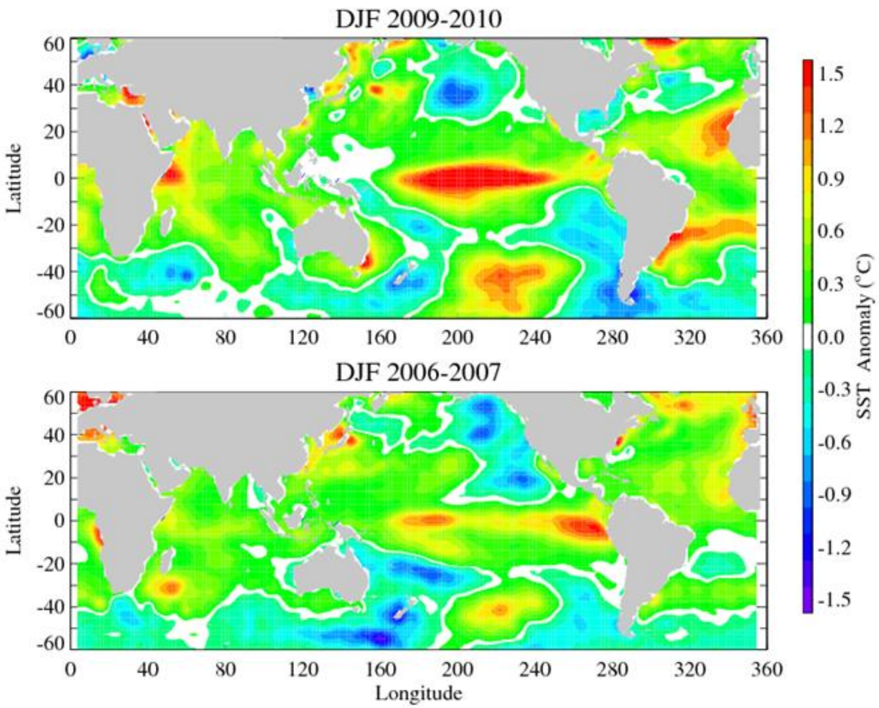


Figure 1. The anomalous SST in DJF 2009-10 (top) and DJF 2006-07 (bottom). The anomaly is relative to the 30-year long term mean. The warm SST anomalies in DJF 2009-10 were concentrated in the CP, while the SST anomalies in DJF 2006-07 were more concentrated in the eastern equatorial Pacific (EP).

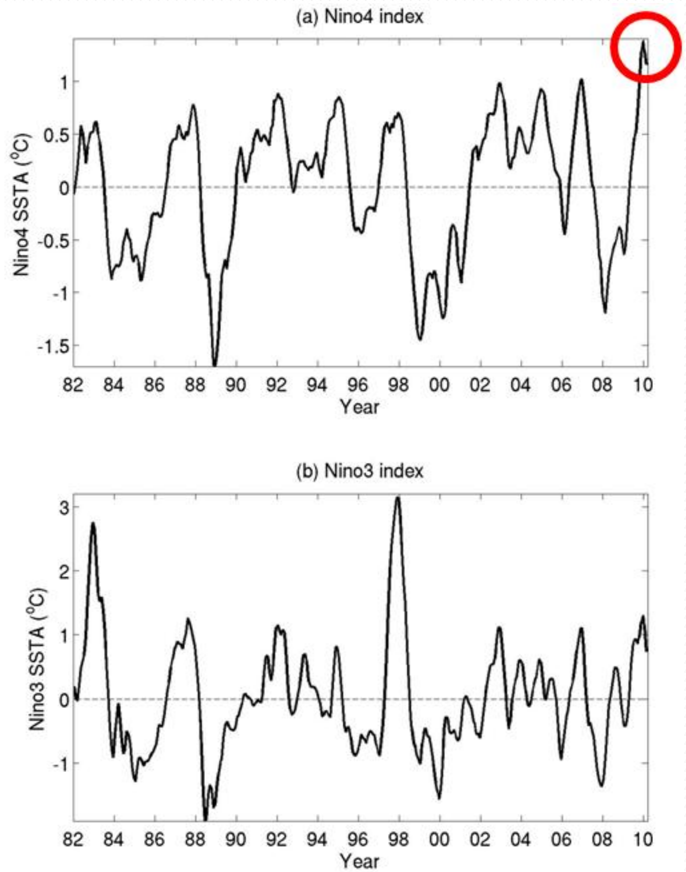
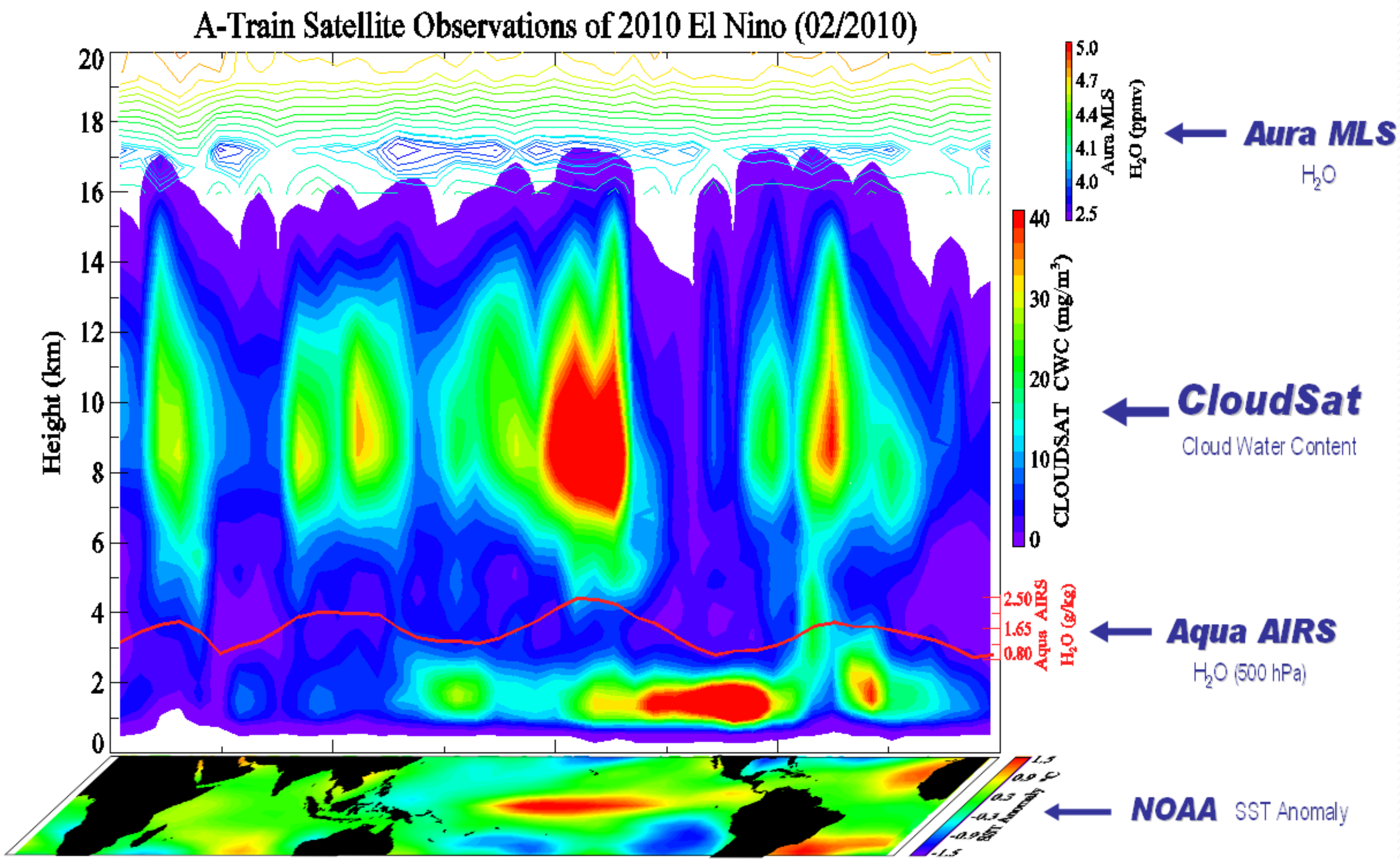
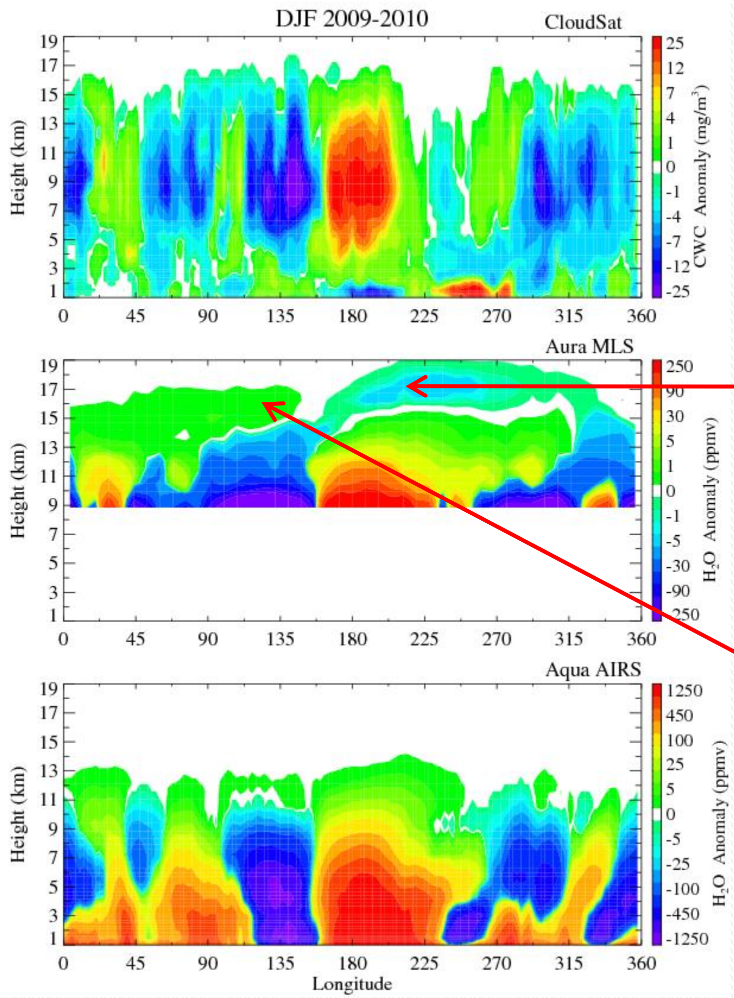


Figure 2. Three-month smoothed (a) Niño4 and (b) Niño3 indices, describing SST anomalies in the CP and EP, respectively (adapted from Lee and McPhaden, 2010). The 2009-10 winter experienced the strongest CP El Niño.

Integrated View From A-Train



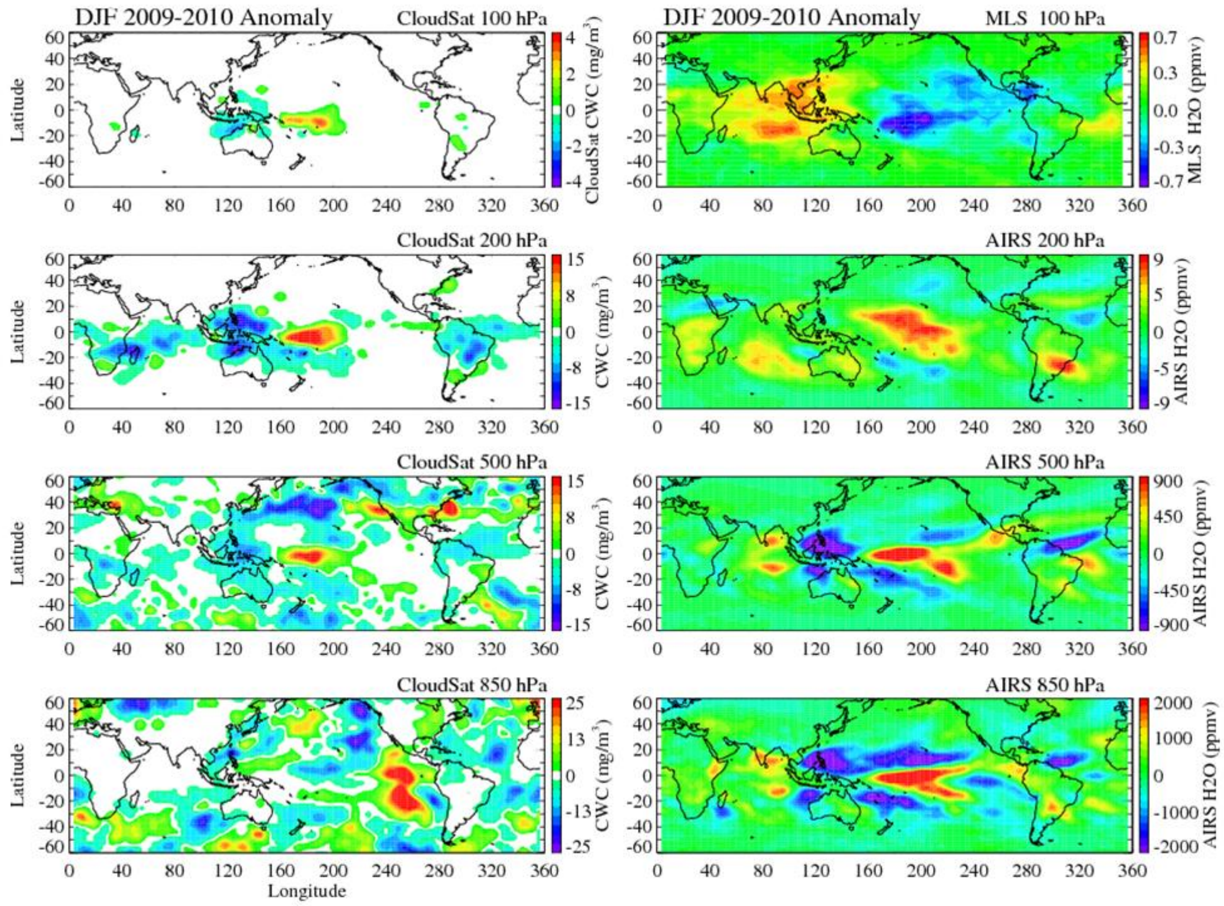
Tropical Mean Anomalies



Averaged (5ºS-5ºN) anomalies for DJF 2009-10

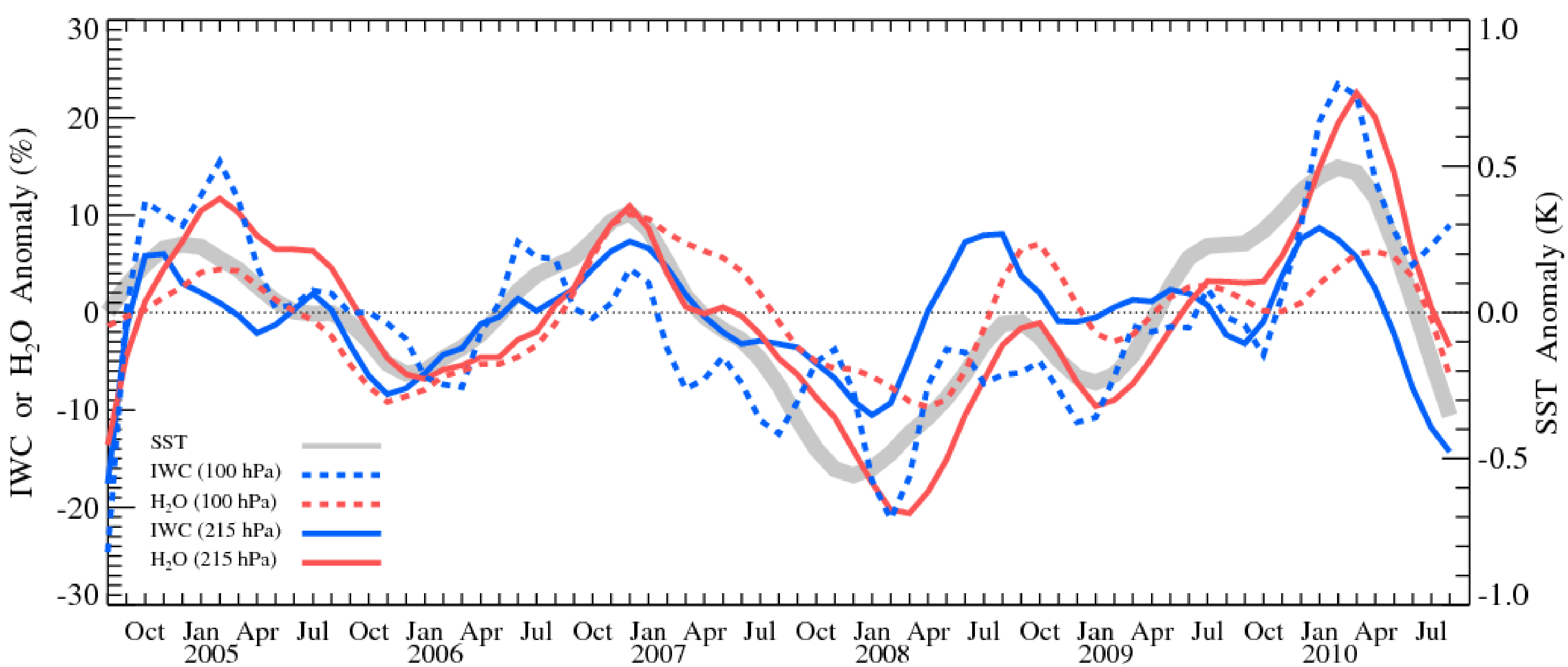
- Enhanced convection in the CP produces increased CWC and water vapor into the TTL. Over the deep convection, the tropical tropopause layer (TTL) is dehydrated.
- Reduced convection in the western Pacific (WP), accompanied by reduction in CWC and water vapor in the troposphere. The TTL is hydrated.
- Response to the El Niño SST warming is observed over the globe.

Spatial Distribution



- Besides deep convective cloud changes, CloudSat CWC shows reduction of low clouds in the northeast Pacific, and increase in the low clouds in the southeast Pacific.
- A horse-shoe pattern is observed in the boundary layer water vapor anomaly field.

Temporal Evolution



- The 2009-10 El Niño marks the strongest UT cloud and water vapor anomalies since the beginning of Aura mission.

Decompose the Dynamic and Thermodynamic Cloud Changes

Analysis framework by *Bony et al.* [2004]

C: a cloud variable (such as L/IWC, cloud fraction, cloud radiative flux or cloud radiative forcing)

ω: a proxy of large-scale circulation

P_ω: probability of a dynamical regime with the value of ω

C_ω: cloudiness in a dynamical regime with the value of ω

$\overline{C}$: tropical-averaged cloudiness expressed as

$$\overline{C} = \int_{-\infty}^{+\infty} P_\omega C_\omega d\omega$$

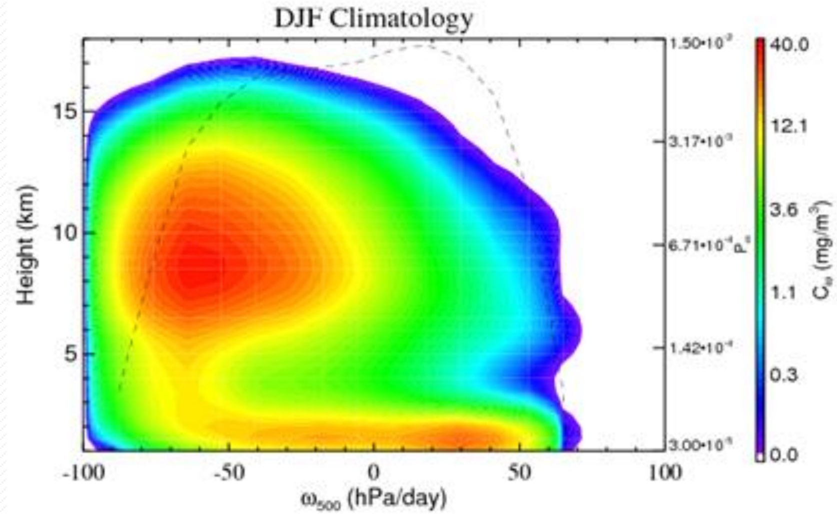
$\overline{\delta c}$: changes of tropical-averaged cloudiness

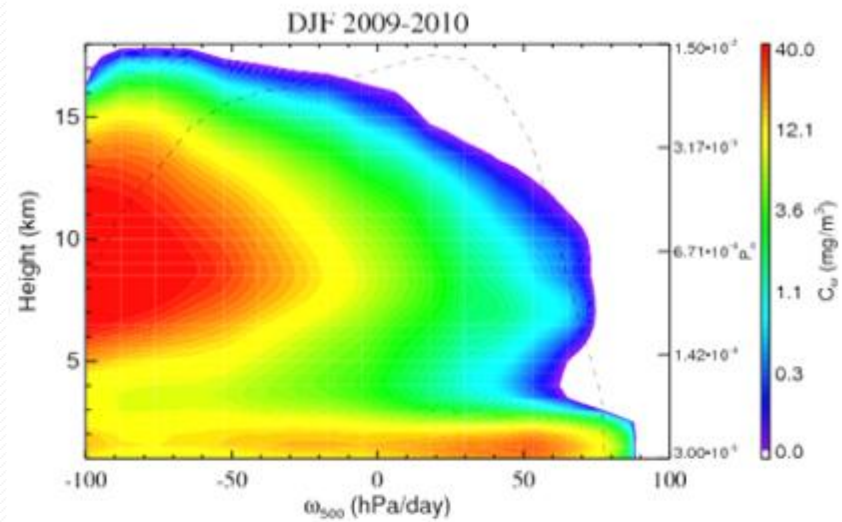
$$\overline{\delta c} = \underbrace{\int_{-\infty}^{+\infty} C_\omega \delta P_\omega d\omega}_{(1)} + \underbrace{\int_{-\infty}^{+\infty} P_\omega \delta C_\omega d\omega}_{(2)} + \underbrace{\int_{-\infty}^{+\infty} \delta P_\omega \delta C_\omega d\omega}_{(3)}$$

(1): dynamic component: changes of circulation regimes

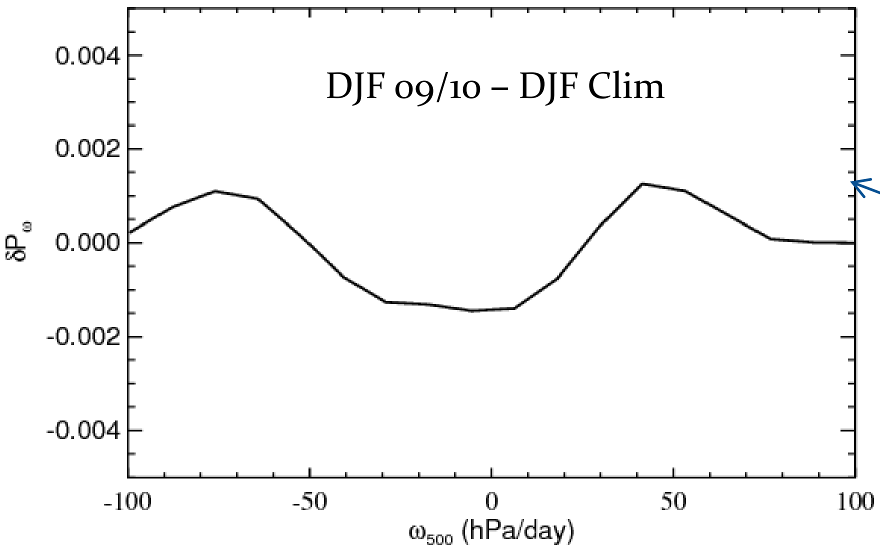
(2): thermodynamic component: changes of cloudiness in a given dynamic regime

(3): co-variation of (1) and (2)



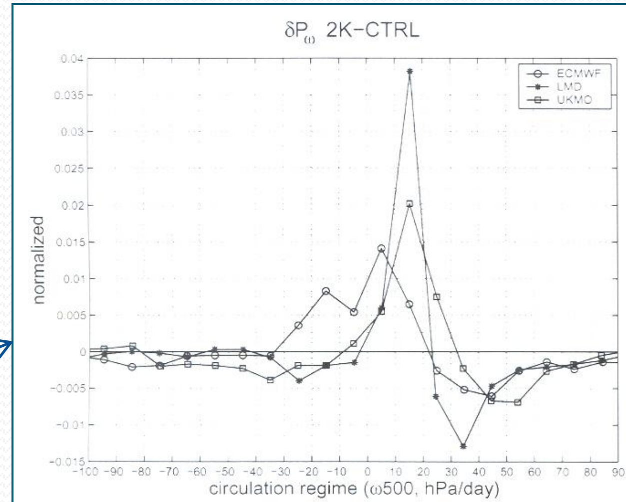


Changes in Large-scale Circulation



Strengthened circulation in 2009-10 El Nino

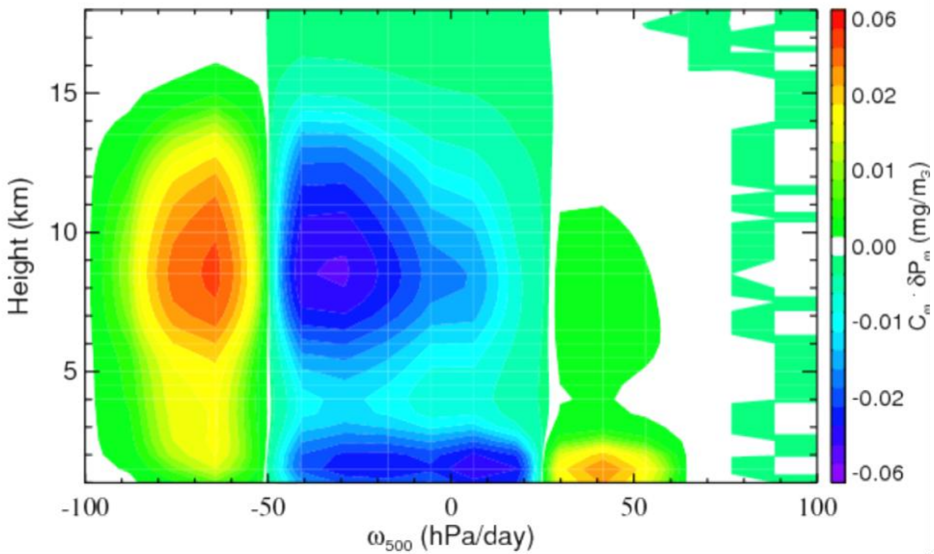
Weakened circulation in global warming in models (+2 K)



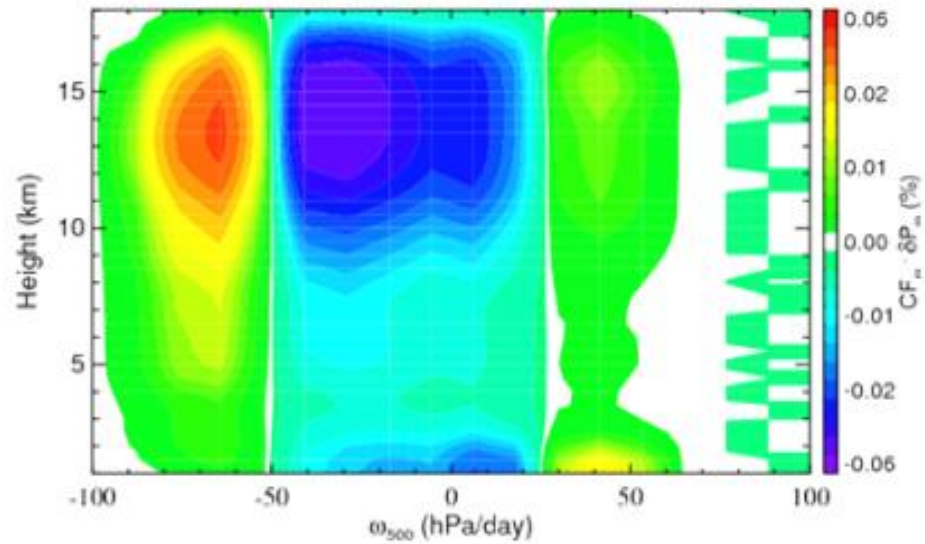
From Bony et al. 2004

Dynamic Cloud Changes

CloudSat Cloud Water Content



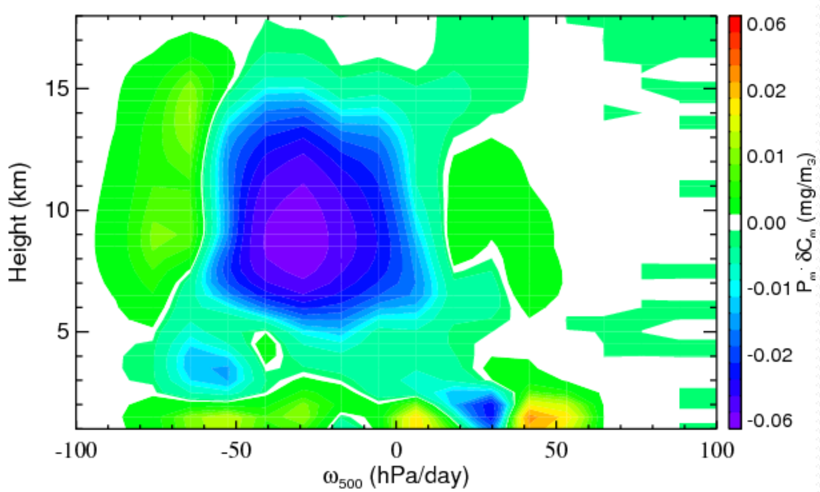
CloudSat/CALIPSO Cloud Fraction



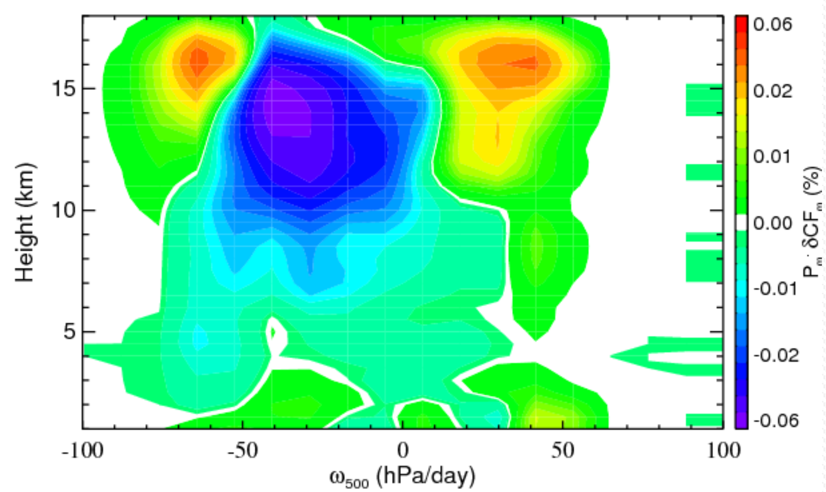
- Increased high clouds in strong upwelling regime
- Decreased high and low clouds in moderate circulation regime
- Increased low clouds in relatively strong downwelling regime

Thermodynamic Cloud Changes

CloudSat Cloud Water Content



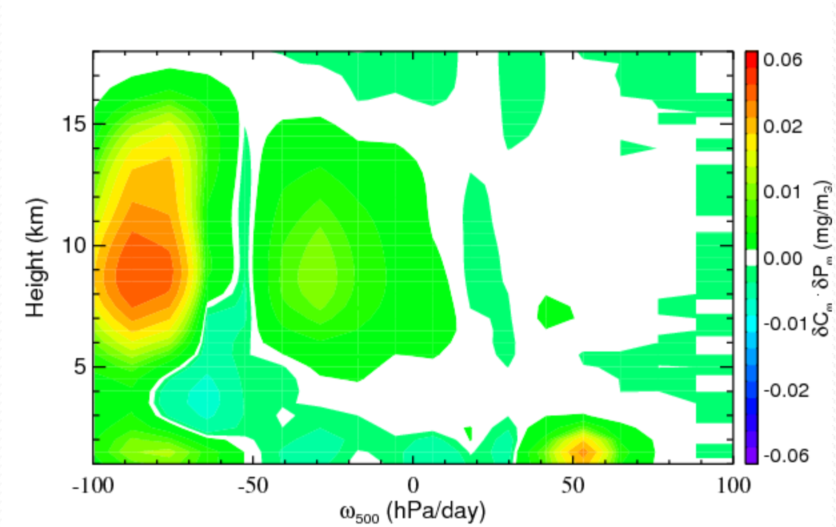
CloudSat/CALIPSO Cloud Fraction



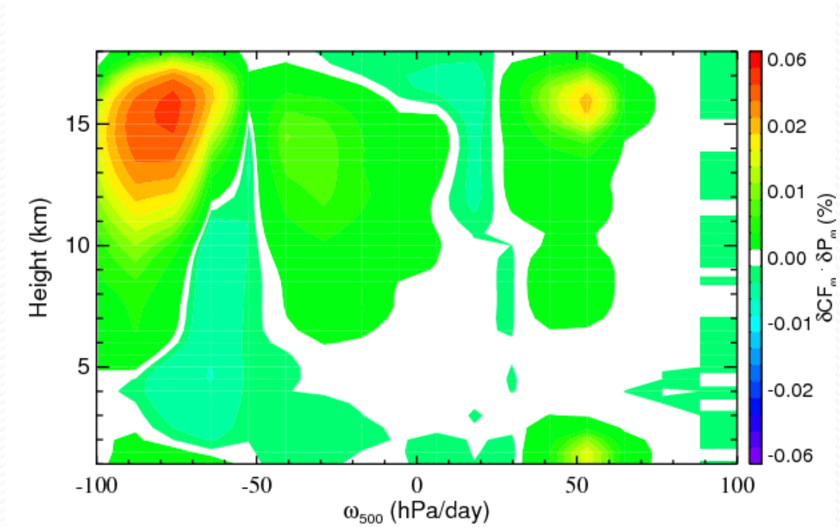
- Increased high clouds in strong upwelling regime
- Decreased high clouds but increased low clouds in moderate circulation regime
- Increased low clouds and cirrus in relatively strong downwelling regime

Co-variations

CloudSat Cloud Water Content



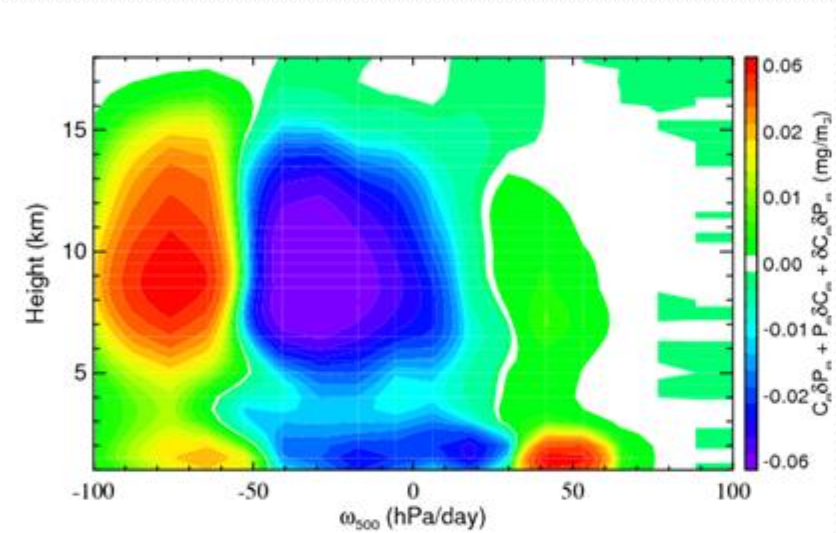
CloudSat/CALIPSO Cloud Fraction



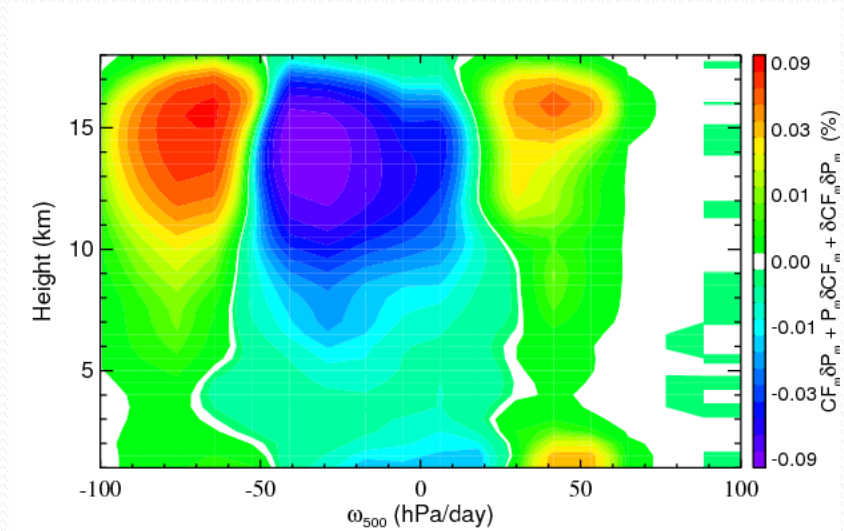
- Positive in most circulation regimes, except for low clouds in the moderate circulation regimes

Total Cloud Changes

CloudSat Cloud Water Content



CloudSat/CALIPSO Cloud Fraction

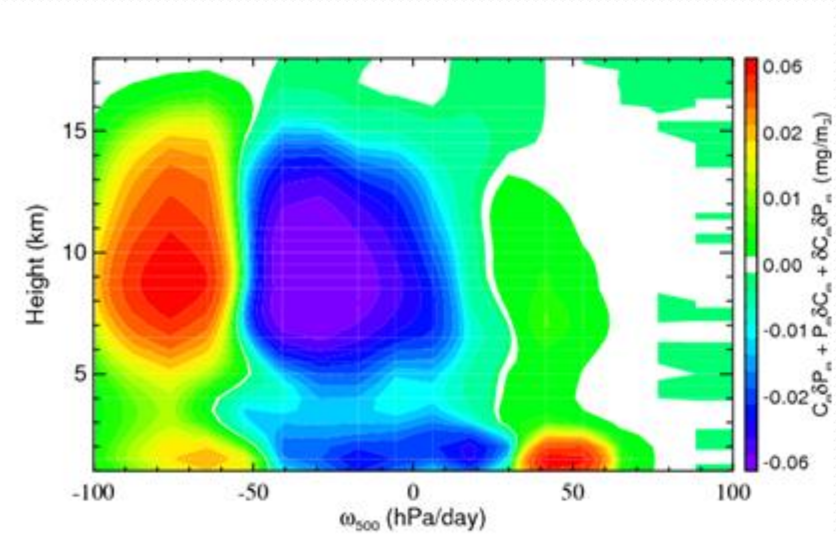


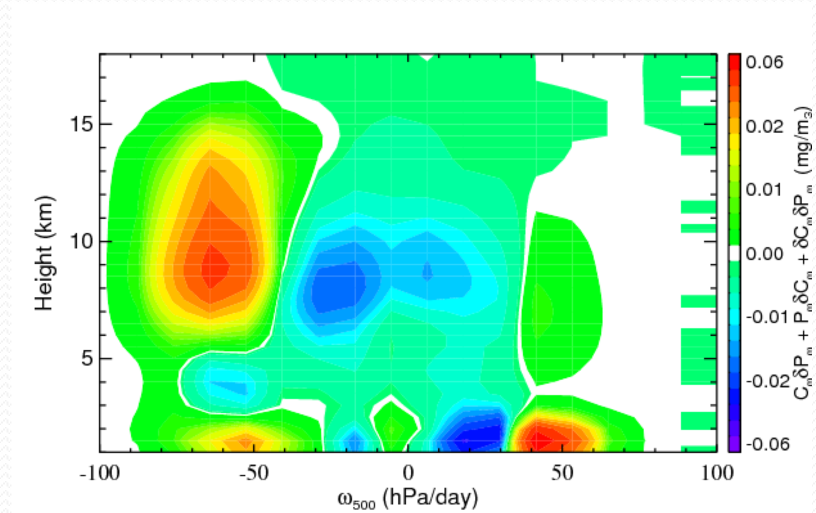
- Increased high clouds in strong upwelling regime
- Decreased high and low clouds in moderate circulation regime
- Increased low clouds and cirrus in relatively strong downwelling regime
- The total cloud change is dominated by dynamic component driven by circulation change

Comparing Two El Niños

DJF 2009-2010

DJF 2006-07





- Qualitatively similar patterns, but different magnitudes

Conclusions

- A-Train measurements clearly show the eastward shift of deep convection from the climatological WP to CP during the 2009-10 El Niño.
- The positive anomalies of tropical-mean water vapor and cloud ice in the UT were strongest since Aura launch.
- The 2010 El Niño contributed to an increase in the tropical-mean stratospheric water vapor.
- The change in circulation (dynamics) dominates the tropical cloud changes, while the circulation change is a result of SST change.
- The co-variation of dynamic and thermodynamic components is non-negligible.